January 14, 1892.

Mr. JOHN EVANS, D.C.L., LL.D., Treasurer, in the Chair.

The Chairman announced the lamented death of H.R.H. the Duke of Clarence and Avondale.

The Fellows determined to adjourn the Meeting forthwith, and directed the Secretaries to send, on behalf of the Society, addresses of sympathy in their deep affliction to Her Majesty the Queen and Their Royal Highnesses the Prince and Princess of Wales.

January 21, 1892.

Sir WILLIAM THOMSON, D.C.L., LL.D., President, in the Chair.

The Treasurer read a Letter which had been sent to him as Chairman of the preceding Meeting, expressing the warm thanks of the Prince of Wales for the sympathy expressed by the Fellows of the Royal Society in his affliction.

The Treasurer offered the Congratulations of the Society to the President on his elevation to the Peerage.

A List of the Presents received was laid on the table, and thanks ordered for them.

The Right Hon. Farrer Herschell, Lord Herschell, whose certificate had been suspended, as required by the Statutes, was balloted for and elected a Fellow of the Society.

The following Papers were read :—

I. "Note on the Audibility of single Sound Waves, and the Number of Vibrations necessary to produce a Tone." By E. F. HERROUN and GERALD F. YEO, F.R.S. Received November 26, 1891.

I.

When investigating the sounds produced by skeletal muscle when caused to contract at varying rates by electric stimulation, we were

thoroughly convinced that a single contraction produced by a single induction shock gave rise to an audible sound of somewhat the same character as the first sound of the heart.*

But it was urged by some physical friends that if the contraction were really a single one, causing a single vibration, it could not be heard, because a *series* of vibrations was necessary to produce a sound, and therefore, unless secondary oscillations succeeded the contraction, the latter would be inaudible.

Now muscular tissue, especially when surrounded by fascia, fat, &c., seemed to be particularly ill suited for sustaining any such series of vibrations, and no such oscillations can be detected on the graphic record of the muscular movement.

When the muscle was stimulated at regular intervals with increasing frequencies the short thuds due to each contraction could be heard separately up to a rate of about forty per second, when these thuds became gradually fused into a dull tone, only clear at somewhat above the rate now accepted as the lower limit of audibility of true tones, viz., forty-one vibrations per second. We adopt this rate, given by Helmholtz,† and neglect the rates of Savart and Preyer,‡ as we believe the tones they heard were probably due to harmonic additions to the rumble of single sound waves caused by 8 or 15 V.D. per second. That the droning sound produced by the lowest organ pipes is not really heard as a true tone seems satisfactorily proved by the well-known fact that they cannot be tuned by the ear alone even of the greatest expert, but only indirectly by the beats which they make with the tones of the upper octaves. The value of such sounds as those produced by a body vibrating slower than forty times per second, and having no true tone capable of differentiation of pitch, can only be to modify and soften the tones of higher octaves, which so occupy the auditory apparatus as to make the separation of the slow single vibrations no longer perceptible.

But the question of the vibrations becoming fused into a musical tone is distinct from that of the audibility of each vibration separately, except in so far as the admission of imperfect union distinctly implies the audibility of the separate vibrations.

To us there did not seem to be the least physiological difficulty in

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* 'Journal of Physiology,' vol. 6, p. 287.

† 'Die Lehre v. d. Tonempfindungen,' &c., Braunschweig, 1870, p. 278: "In der künstlerischt vollendeten Musik des Orchesters ist deshalb auch der tiefste Ton welcher angewendet wird, das E, des Contrabasses von 41 Schwingungen, und ich glaube mit Sicherheit voraussagen zu können, das alle Anstrengunen der neueren Technik, tiefere gut musikalische Töne hervorzubringen, scheitern müssen, nicht weil es an Mitteln fehlte passende Luftbewegungen zu erregen, sondern weil das menschliche Ohr seine Dienste versagt."

‡ 'Physiologische Abhandlungen,' Theil 1, pp. 1—17.

the belief that a single wave could be transmitted, so as to excite the terminals of the auditory nerve.

On the other hand, if one complete vibration does not stimulate the hearing apparatus, a distinct logical difficulty presents itself when we attempt to explain how multiples of no stimulation can give rise to such an immense variety of definite effects on the cochléa and the brain. If expressed as a formula, the inaudibility of single vibrations appears absurd, 1 V.D. $= 0$ but 528 V.D. $= C''$.

Being satisfied that a single contraction of muscle could be heard as a thud, and that the single thuds could be heard separately until a rate was attained that fused them into a tone, it was thought advisable to examine some physical instruments for the production of sound, which admit of adjustment to various rates above and below the lower limit of appreciation of tone.

It is well known that, with organ pipes 32 feet long, or with a monochord, the string of which by weighting has been made to vibrate below thirty times per second, sounds are heard having the character of an imperfectly fused rumble, in which the ear can distinctly detect the separate vibrations, but no distinctive tone.

Some exception might be taken to the evidence furnished by the use of pipes or strings as to the audibility of the separate waves on account of the possibility of harmonic sub-division of the column of air or string giving the octave as the chief harmonic. We, therefore, preferred to use tuning forks, in the case of which this objection does not obtain, as their vibrations are probably the most purely pendular, and the first harmonic of the fork is so much higher in pitch ($6\frac{1}{4}$ times the vibration frequency of the fundamental tone), as to be always readily recognisable if present. With a fork of 30 V.D. per second, a sound is produced which is audible through the air, but much more distinctly so by placing the base of the fork in contact with the head or by fixing the fork firmly in a block of wood which was auscultated by a binaural stethescope. The character of the sound remained the same when transmitted by these different methods. At this rate of vibration (thirty per second), the impression is just becoming continuous, but not sufficiently so as either to prevent the recognition of the separate vibrations or to produce a distinctive tone. By the use of brass weights, firmly clamped at different heights on the prongs of the fork, its rate of vibration was reduced to 28, 24, and 20 V.D. per second respectively, the rate being estimated by being recorded on a smoked surface moving at a known velocity. The effect of this reduction of rate is that, while the intensity of the sound becomes enfeebled, the separation of the constituent vibrations becomes more distinct and unmistakable. Thus the audibility of the fork becomes less and less as the rate is lowered, but the sound always preserves the same toneless and interrupted character. These effects of reducing the rate of

vibration ought not to take place if the audition depended upon adventitious vibrations set up in bodies in contact with the fork. But, if each vibration transmits a distinct movement to the ossicles of the ear, both these effects should be expected, and are easily explained. And the fact that, with the low rates of vibration, the waves in air are so long and the changes of pressure so gradual that the sound ceases to be appreciated through the air, while still distinctly audible through the bones of the head, also becomes clear.   We may then conclude that when the rate of vibration is reduced to that at which the individual waves are no longer heard, the fork has become absolutely inaudible ; while the power of differentiating tone is lost long before this limit has been reached.

It might be alleged that, although the fork gives rise to a series of pure pendular vibrations, these set up secondary vibrations of higher frequency in the membrane of the tympanum, or some medium through which the waves pass.

To test this point, we constructed a kind of phonautograph in imitation of the tympanic membrane. It consisted of a circular metal frame, over which a thin india-rubber membrane was stretched with very slight and adjustable tension.   An extremely light lever, armed with a fine writing point, and poised on jewelled bearings, similar to the escapement of a watch, was brought into connexion with the centre of this membrane, so as to record its slightest movement on a smooth, lightly-smoked, moving surface.   With this apparatus we were able to record the vibration of forks at the rate of 25 and 30 V.D. per second, when the fork was held about 2 or 3 cm. from the membrane, and the vibrations thus transmitted through the medium of the air.   The tracing was made up of a series of regular undulations, entirely free from any indication either of over-tones or "self-tone" of the membrane.   It appears, then, exceedingly improbable, if such a comparatively rough mechanism can transmit these slow toneless waves without exhibiting any tendency to persistent vibration of its own, that this should occur with the membrana tympani, the structure of which is adaptively modified so as to check, in particular, any such effect, and which is capable of differentiating such a wide range of tones with equal precision.

From the foregoing it would appear that not only is there no difficulty in understanding how these waves, which are too slow to produce a tone, are carried to the nerve, but also that the pure pendular vibrations of the tuning fork furnish conclusive evidence of the audibility of each single wave when reduced to a rate at which tone can no longer be discriminated.

In order to obtain single vibrations of the more rapid rate of higher notes (*i.e.*, vibrations of short durations isolated from the series causing the note) we employed a disk siren in which any number of

holes could be left open or closed at will.   The wheel was turned by hand, about twenty-five rotations of the disk being the maximum attainable with the required regularity.

By leaving only one hole open, only one puff was made at each revolution.   By varying the rate of rotation, waves of different dura-tion, *i.e.*, corresponding to vibrations of different pitch, could be produced.   No matter how the rate of revolution was increased, up to the maximum, twenty-five per second, only the single puffs could be heard ; at first quite separate, then as a soft purr, and at the quickest rate like a kind of rapid patter.

With this siren, the sound caused by the single impulse is most distinct and clear, and its invariability in character with varying rate and varying blast of air particularly noticeable.   The single puffs of a duration not exceeding $\frac{1}{1000}$ second were thus perfectly audible.

As the rates just referred to were estimated from the number of revolutions made by the driving wheel, we thought it advisable to control this method of measuring the length of the waves by ascer-taining the note produced by the siren when all the holes were open while the disk revolved at the same rates.   It was thus found that clear tones could be heard varying with the rate up to the maximal attainable limit, somewhat above the note C''', *i.e.*, 1056 per second.

II.

No doubt adventitious secondary oscillations followed the single puffs for a short period, and probably gave them character as well as making them more distinctly audible.   Hence we wished to hear what character the tones would have if caused by a short series of these vibrations.   We commenced with a number of holes open which, at our maximal rate, would have a duration of $\frac{1}{100}$ second. This gave a tone similar to, and quite as distinct as, that produced when all the holes were open.   We then gradually reduced the number of holes used, and we found a fact which, as far as we know, has not been previously observed, and for which we were not prepared by the importance given by our physical friends to the necessity of *a series* of waves in the production of sounds.   When only *two* holes remained open, the variation in tone following changes in rate was perfectly distinct, and a note even higher than C''', corresponding to 1056 V.D. could be heard perfectly.   That is to say, a series made up of two puffs which lasted $\frac{1}{1056}$th of a second each, or less than $\frac{1}{500}$th of a second for the series, was capable of stimulating the terminals of the auditory nerve in such a way as to make the tone C''' readily recognisable.

When the single hole and the double hole were tried alternately, the result was striking.   The pitch of the note caused by the short series of two puffs rose and fell with the increase or decrease of the

rate of rotation, while with the single hole the puff, though distinctly audible, remained the same monotonous sound, independent of sudden variations of the speed of the disk. The only change in character was that the intensity diminished with the lower rates of vibration.

From the foregoing, we have been led to the following conclusions:—

1. When sound is produced by a vibrating body, each individual wave of the series causing the tone stimulates the terminals of the auditory nerve. If the single vibrations are of such a nature as to be inaudible, no tone can be heard.

2. The individual vibrations can be heard when the rate of vibration is too slow for a distinctive tone to be appreciated.

3. The immediate succession of two waves, at rates of vibration above fifty per second, gives rise to a sensation of tone having the same pitch as that yielded by a prolonged series at the same rate.

That is to say, one can distinguish the tone produced when only two vibrations of a series reach the terminals of the auditory nerve.

4. Having worked for some time with rates of vibration near the limit of the lowest tones, we are forced to admit that we have not attained the skill (said to be attained by practice) of distinguishing small changes in pitch with rates of vibration below fifty per second; at least, in the case of pendular vibration, such as is produced by tuning forks or muscular contraction.

II. " On the Mechanism of the Closure of the Larynx. A Preliminary Communication." By T. P. ANDERSON STUART, M.D., Professor of Physiology, University of Sydney, N.S.W., Australia. Communicated by Professor E. A. SCHÄFER, F.R.S. Received December 10, 1891.

By a series of papers ending with that by myself with Dr. A. McCormick ('Journ. Anat. Physiol.,' January, 1892), it has been finally determined that the time-honoured doctrine of the closure of the larynx by a lid-like action of the epiglottis is quite untenable; but, so far as I am aware, no satisfactory account of how after all the larynx is closed voluntarily and reflexly has as yet been given. The determination of the positive side of the question was nevertheless the necessary sequel of the determination of the negative side; having settled how it *is not* closed, one naturally proceeded to enquire how the larynx *is* closed, since closed it at times must be, and that at its very entrance.

In the literature of the subject I find that there is considerable looseness of diction. "Closure of the larynx" may mean either " closure of the glottis," " closure of the vestibule," or " closure of